Simulation of Hadron Calorimetry for the CMS Detector at the LHC

For Jets and Missing Et Measurements

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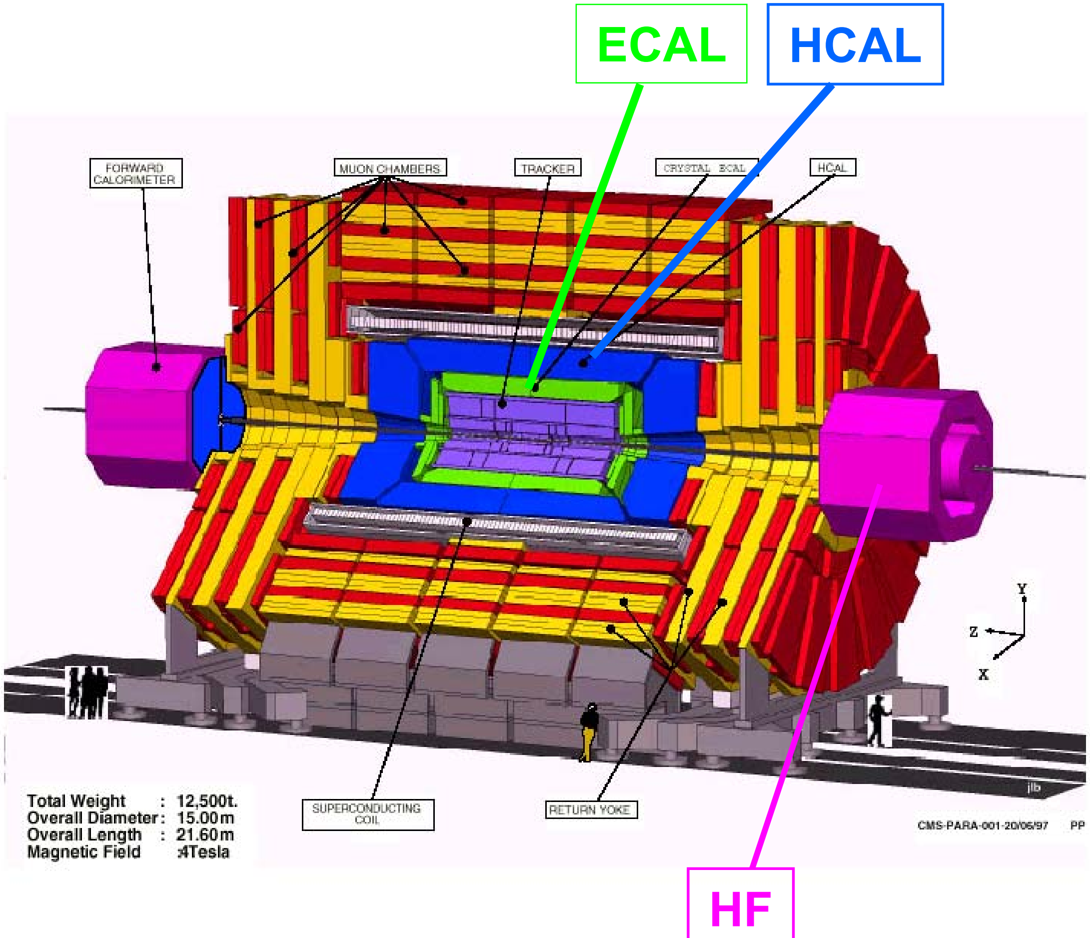
CMS Detector

Calorimeter detects jets from quarks and gluons.
Neutrinos are inferred from missing Et.



ECAL

comprises 80000 $PbWO_4$ crystals. Each crystal is ~2x2x23cm: 26 X_0, 1.1 λ_0

HCAL

is a sampling calorimeter comprising a brass absorbers and scintillator tiles with optical fiber read out.

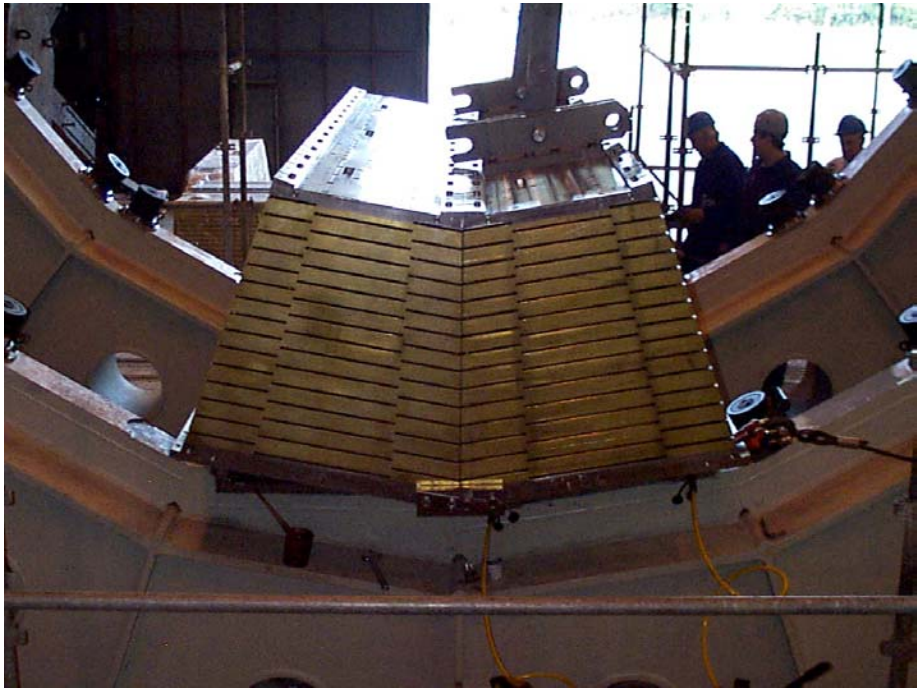
HF

is a quartz fiber calorimeter with iron absorber.

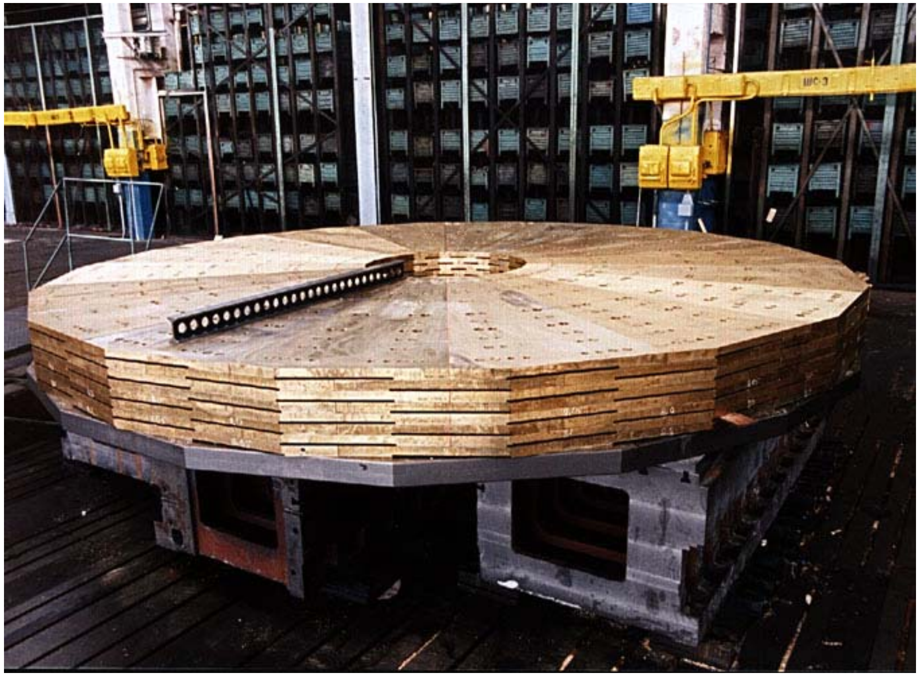
HCAL Production

Production of absorbers and scintillator tiles have started.
Half of barrel wedges (total 18) will be delivered to CERN in November, 2000.

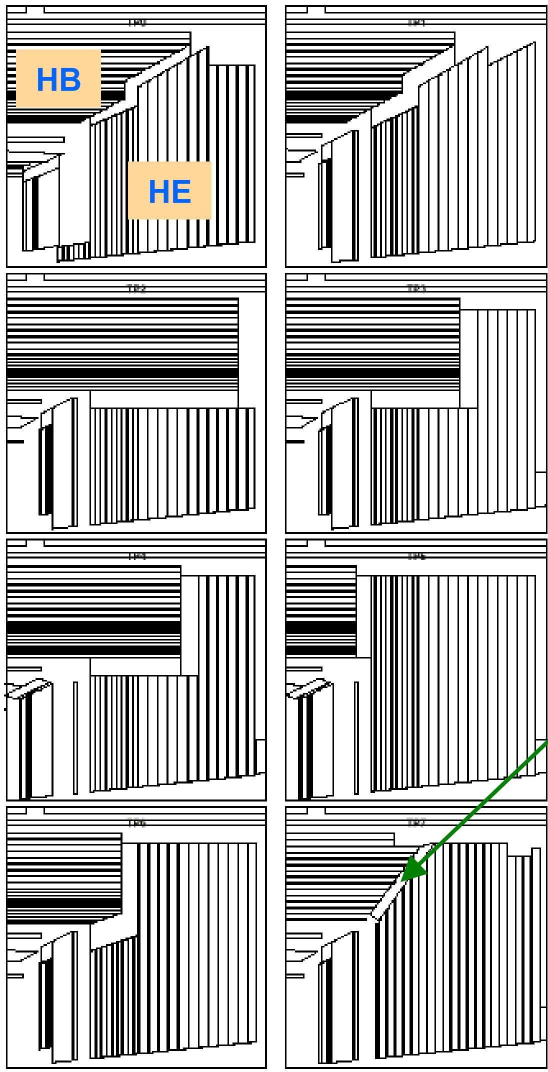
Barrel wedges
Trial assembly
at Felguera in Spain



Endcap absorbers
assembly
at MZOR



Use of GEANT3 Simulation



We have used GEANT3 for:

- optimizing the calorimeter geometry.

  For example, geometry in the barrel-endcap transition region.
  We tried several geometry and checked calorimeter response to single hadron and jets.
  We chose this for the final design.

Now we use GEANT3 simulation to develop

- algorithm for trigger on jets and missing transverse energy.

- algorithm for jet energy scale correction.

For these, we simulated >10E6 events.

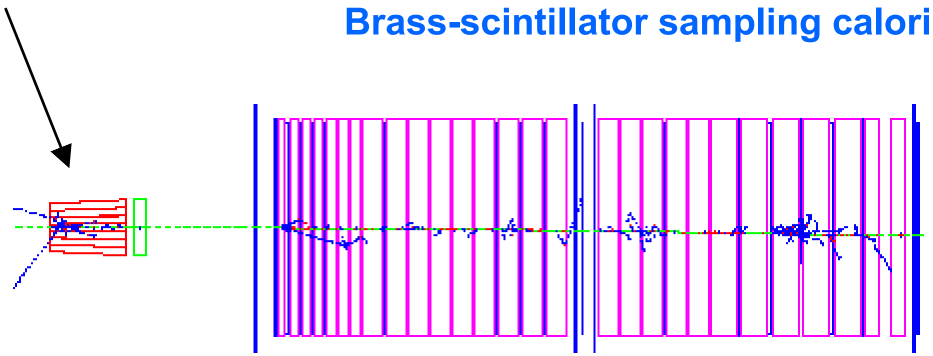
Test Beam Setup

Before we simulated the CMS geometry, we had simulated several test beam setup. One of them is shown here.

The test beam data were taken in 1996 at CERN with pions (E=20-300GeV), muons (300GeV) and electrons, and the setup was simulated with GEANT3.

ECAL
7x7 crystal matrix

HCAL
Brass-scintillator sampling calorimeter

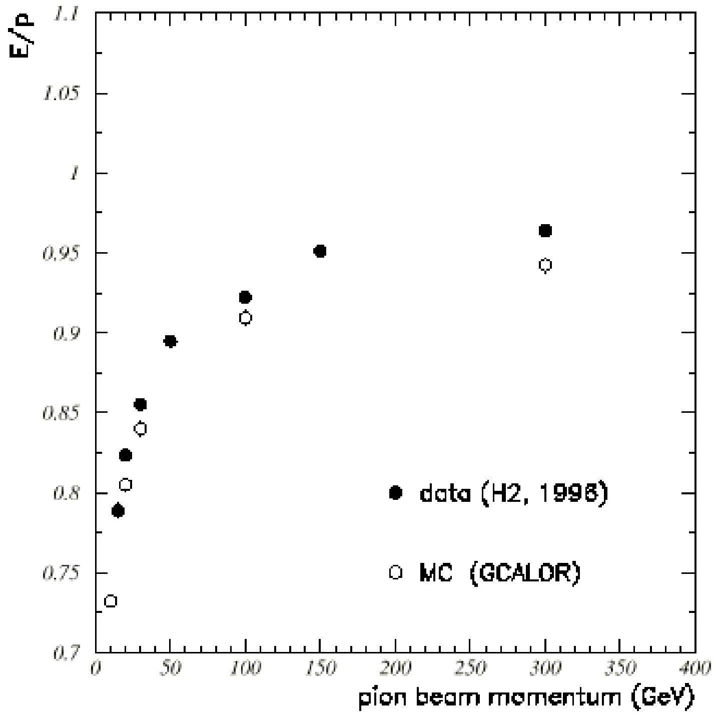


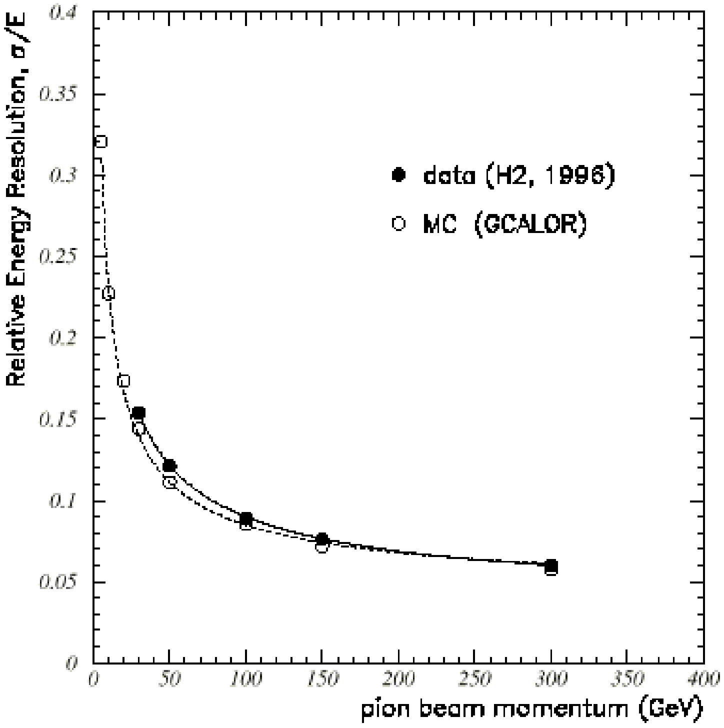
A muon passing through the detector

Layer number	Absorber thickness	Scintillator thickness
HCAL 1	2 cm Cu	4 mm SCSN-81
HCAL 2-7	3 cm Cu	4 mm SCSN-81
HCAL 8-21	6 cm Cu	4 mm SCSN-81
HCAL 22-27	8 cm Cu	4 mm SCSN-81

Test beam data vs. GCALOR

Data and GCALOR simulation showed reasonable agreement in linearity and resolution, even using relatively high Ecuts for GEANT3.

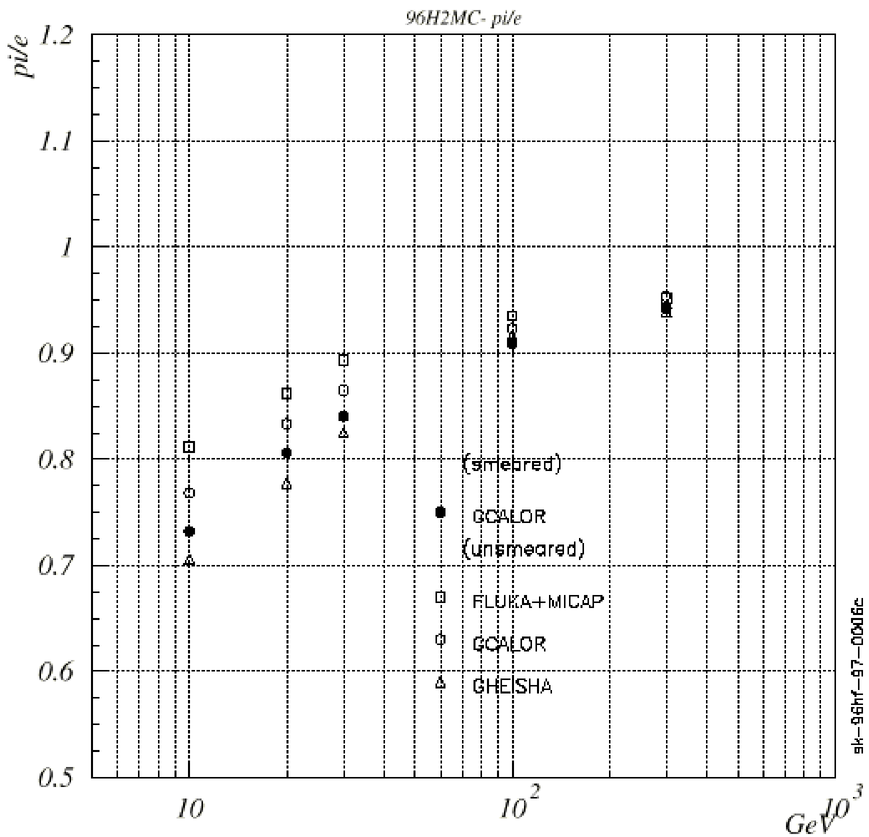




(GEAN3 Cuts, 1MeV for EM, 10MeV for HAD)

Comparison of Hadron Shower Models in GEANT3

pi/e

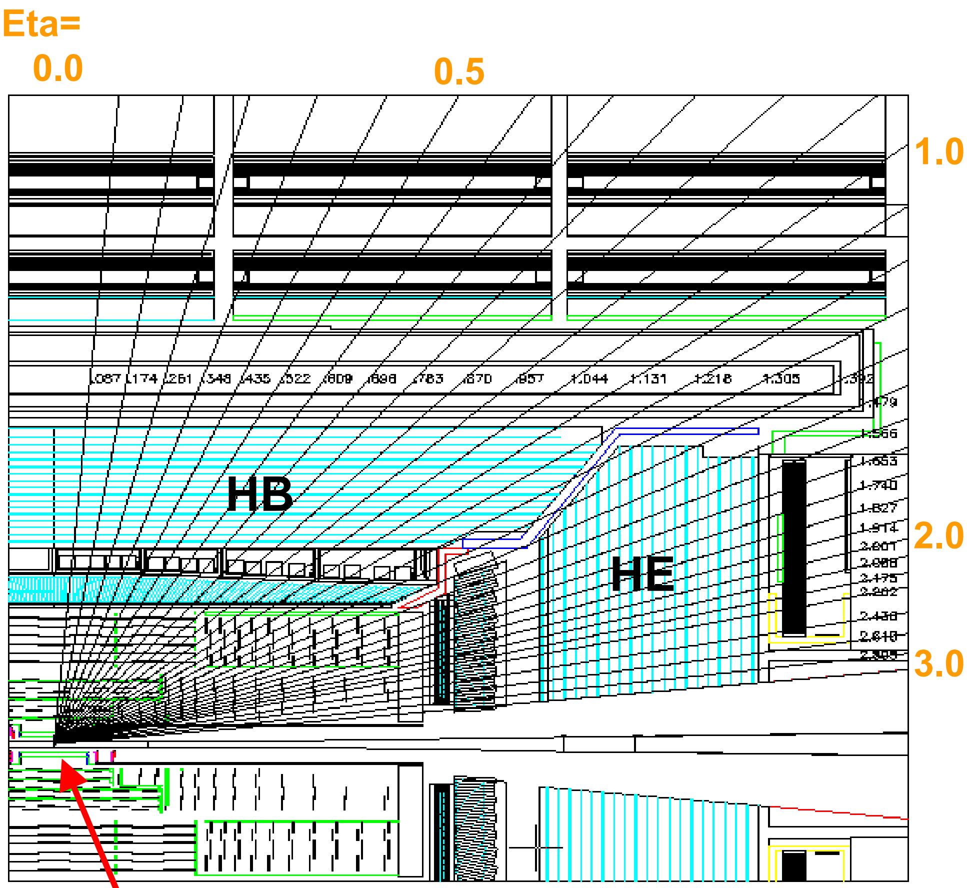


This shows ratio of responses to pions and electrons by three models in GEANT3: FLUKA+MICAP, GCALOR and GHEISHA.

"smeared" points include electronics noise in the test beams data. Since we expect noise level in the CMS experiment will be much smaller than this particular beam test, "unsmeared" points represent the CMS case.

Three models differ by ~8% at 10GeV.

CMSIM simulation



Proton-proton interactionpoint
7TeV + 7TeV

Pseudo rapidity
eta=-ln(tan(theta/2))

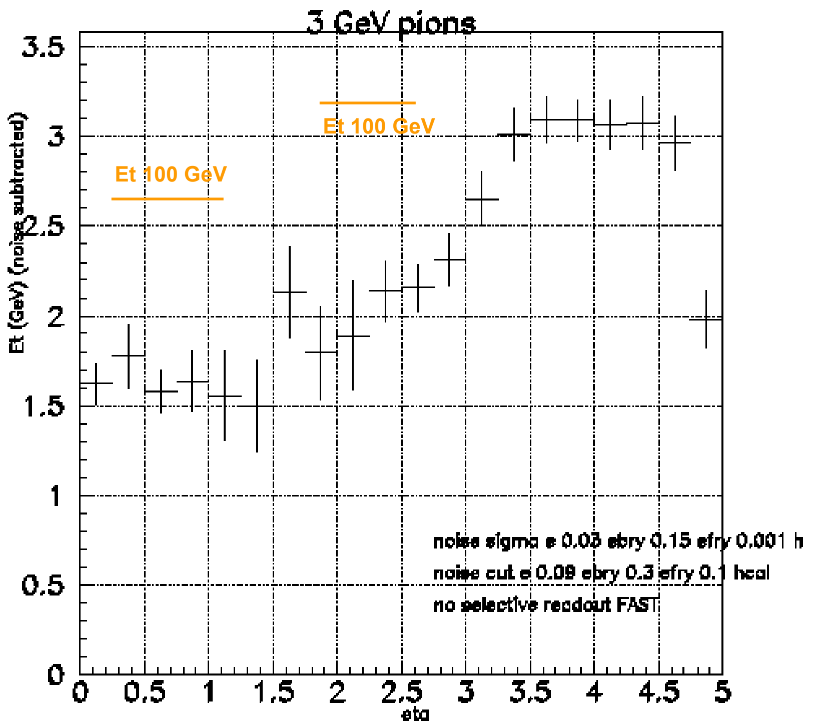
CMSIM is a GEANT3 based simulation program.

More than 1 million p-p interactions have been generated with very detailed description of the detector geometry.

All simulated events have been reconstructed with a new object oriented reconstruction program (ORCA).

Eta dependent energy scale

Response to E_T=3GeV pions in CMS.



E= 3 7 30 82 227 GeV

Because of non-linear response shown on page 6, CMS calorimeter response has strong pseudo rapidity (eta) dependence for give E_T.

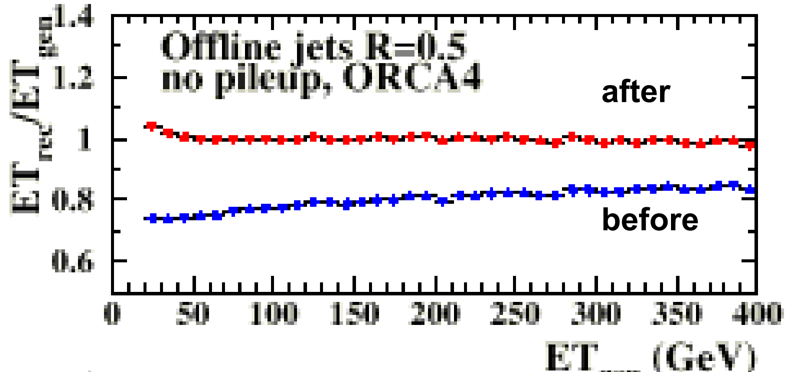
For pions of 3 GeV transverse energy (E_T=E*sin(theta)), the response changes from 1.5 GeV at eta=0 to 3 GeV at eta >3. Note that E_T and E are same at eta=0, while E_T=3GeV becomes E=30GeV at eta=3.0 and E=227GeV at eta=5.0.

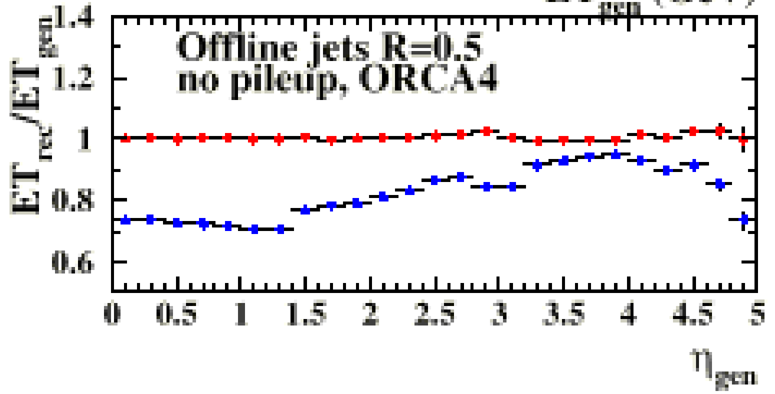
This strong eta dependence is a reflection of non-linearity shown on page6.

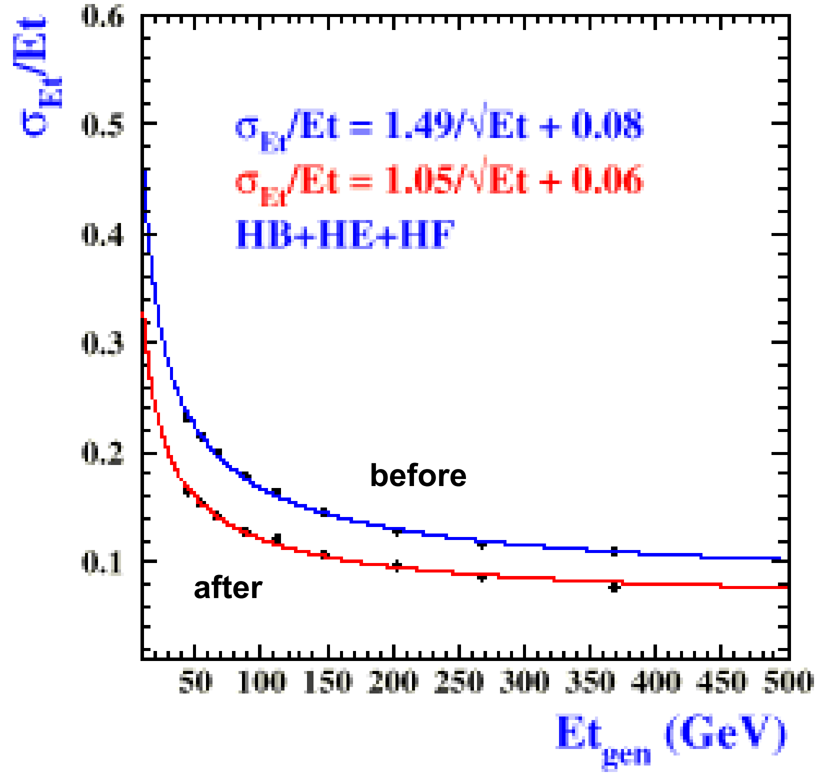
Response to Et=100GeV is also indicated in this figure. The variation is much smaller, ~10%.

Energy Correction

"Jet" is mixture of mainly charged pions and gamma from neutral pion decays. Calorimeter response before energy scale correction are shown in blue: a) dependence on jet ET and b) dependence on eta. We calculate ET scale correction factors, which depend on both ET and eta and apply it to jets. c) shows improvement of resolution after the correction (in red).

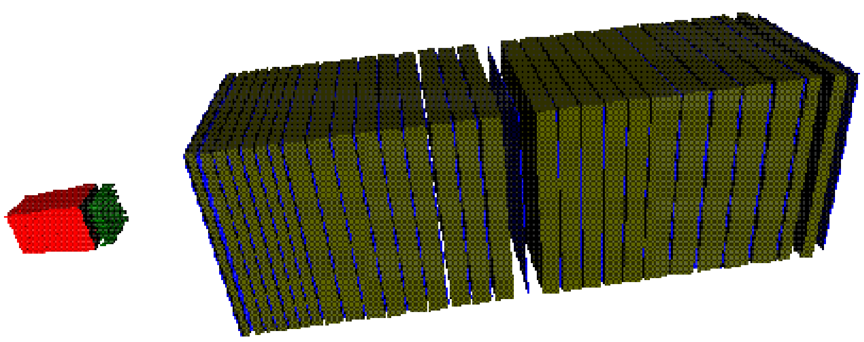






GEANT4 Simulation

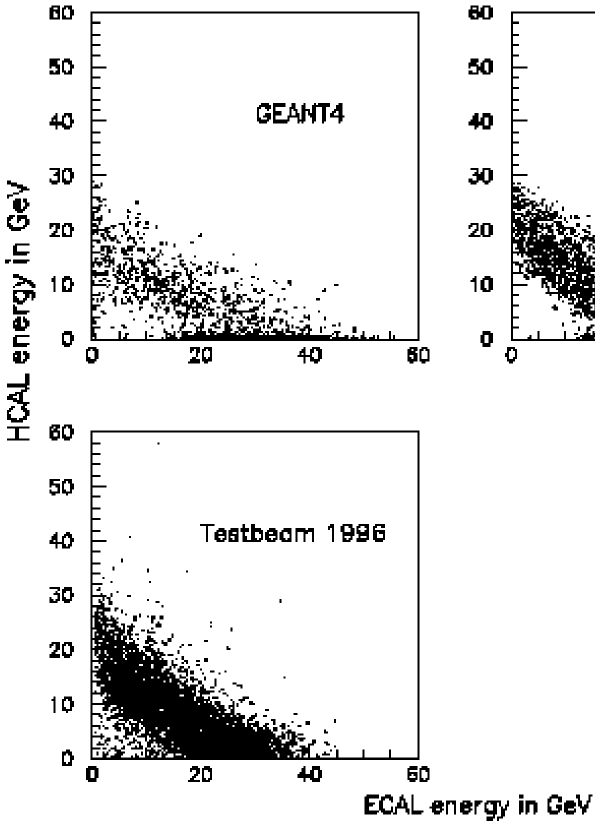
It is critical for CMS to simulate energy scale correctly in order to understand jet physics. Unfortunately, our test beam data with PbWO4 crystals suffered from electronics noise to test hadon shower model in simulation program. We plan to take test beam data with production wedges with final electronics to verify (or tune) hadron shower model in GEANT4.



CMS HCAL 1996 testbeam geometry

In the following, we show very preliminary results from GEANT4 simulation with old test beam setup.

GEANT4: HCAL vs ECAL



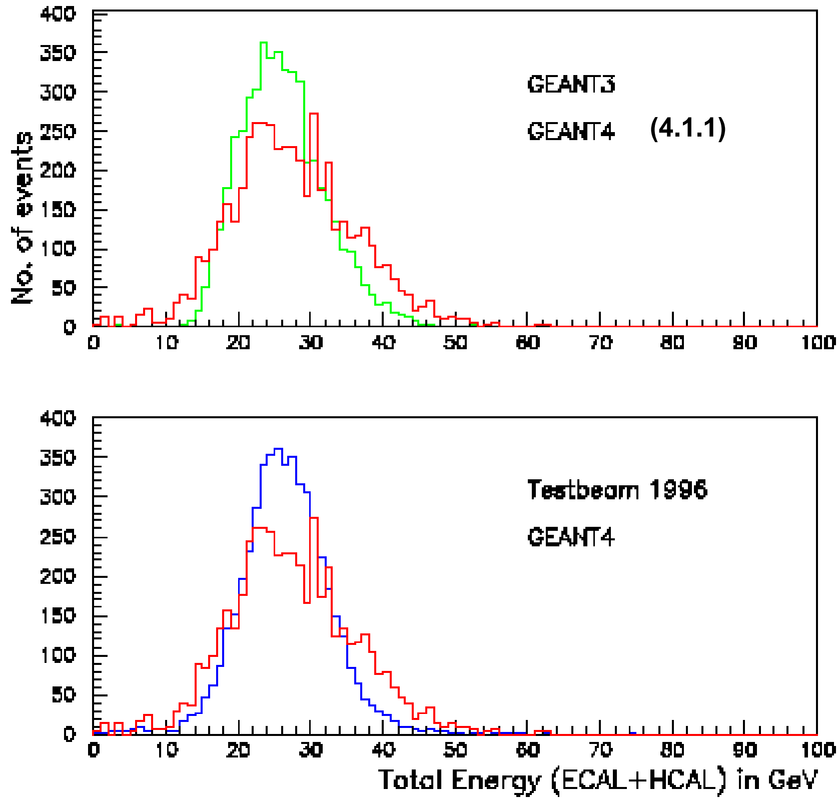
Comparison of energy in ECAL with energy in HCAL for 30 GeV pions

Data was generated with GEANT 4.1.1, a cutoff of 2 mm was used on range of particles.

- Energies:
  - 200 GeV muons
  - 10 to 100 GeV pions
  - 10 to 100 GeV electrons
- Magnetic Field:
  - 0 tesla
- Configuration:
  - Only HCAL
  - ECAL + HCAL

Statistics: $\sim$ 2000 events for each case were generated.

GEANT4: 30GeV pions

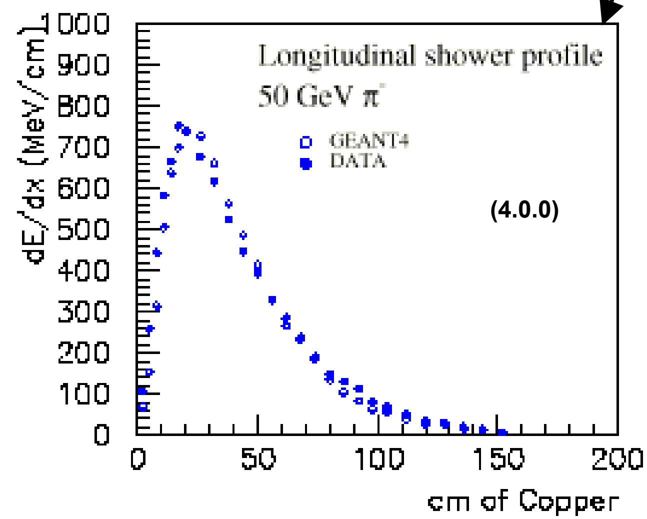


Total energy (ECAL+ weighted HCAL) for 30 GeV pions,
– GEANT4, – GEANT3, – Testbeam

G4 shows wider distribution than G3 and data. We need to check our program.

Note that our previous G4 simulation for HCAL alone with earlier release (4.0.0) of G4 showed good agreement between G4 and data.

So, we need to debug our current code and also try the latest version of G4 (4.2).



Conclusion

GEANT3 showed reasonable agreement with CMS test beam data.

- Three hadron shower models predict e/pi different by ~8% for pions at 10GeV.

Energy scale is critical for jet physics.

- CMS is developing algorithm for energy scale correction using detailed GEANT3 simulation.

CMS is testing GEANT4.

- Need better test beam data to verify hadon shower model in G4 and tune the model.
- Production modules with final electronics will be in test beam after 2001.